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MODELLING THE CONTAINER FLEET MANAGEMENT PROBLEM USING A STOCHASTIC DYNAMIC APPROACH

by

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ABSTRACT

We propose a two-level approach for the global, integrated planning of the land distribution and transportation of containers. The topmost level is concerned with the strategic/tactical planning issues: depot selection, allocation of clients to depots, determination of major interdepot empty container flows, etc. The second component corresponds to the level of the day-to-day operational planning of the company's activities. The paper focusses on the description of the operational decision-support system and its two main components: the dynamic stochastic empty container allocation model and the model for routing loaded and empty containers.

KEYWORDS Fleet Management; Land Container Transportation;
Decision–Support System;
Dynamic, Stochastic Vehicle Allocation; Routing Model.

RESUME

Nous présentons une approche à deux niveaux pour la planification globale et intégrée de la distribution et du transport terrestres des conteneurs. Le premier niveau traite les questions de planification stratégique et tactique: choix de dépôts, affectation des clients aux dépôts, détermination des principaux mouvements inter-dépôts de conteneurs vides, etc. Le second niveau couvre la planification opérationnelle des activités quotidiennes de l'entreprise. Dans cet article, l'accent est mis sur la description du système d'aide à la décision opérationnel et de ses deux composantes principales, le modèle dynamique stochastique de répartition des conteneurs vides et le modèle de confection de routes pour les conteneurs pleins et vides.

MOTS CLES Gestion de flotte; Transport terrestre de conteneurs;
Système d'aide à la décision;
Allocation dynamique et stochastique des conteneurs; Routes de véhicules.

INTRODUCTION

Since the seventies, freight transportation activities have seen many fundamental changes both in terms of technology and of organization. In particular, one must note the increasing use of multimodal transportation routes and of containerized transportation practices. This is particularly true in the area of maritime shipping.

The reasons for the wide use of containers, by all modes of transportation, were pointed out by Frankel as early as 1968. Containers offer obvious advantages of rationalization of shipment, security, facility of handling, facilitation of multimodal transportation, etc. Yet, they also require that a number of specific problems be solved, such as the management of the fleet, the balance between ownership and leasing, the determination of multicarrier transportation routes, fleet pooling issues, the empty container repositioning after and before a loaded shipment, etc. The high cost of acquiring, maintaining, handling and transporting containers make the issue of adequate container management a very relevant problem.

The planning of the land transportation part of the international maritime shipping of containers is an extremely complex activity, especially if one aims to simultaneously optimize the cost and the service aspects of operations in a competitive environment. In this context, Operations Research models and methodologies offer very useful instruments that a company may use to analyze, evaluate and plan its strategic and operational policies. These models and methodologies display superior performances when they are integrated into decision-support systems which feature interactive-graphic interfaces and which are connected to a reliable management information system (M.I.S.) and to up-to-date databases encompassing all the elements of the system: transportation network, supply, demand, shipment and cost parameters, etc. (Crainic and Dejax, 1989). This view is similar to those of, among others, Jarke (1982), who reviews container management problems and who insists on the necessity for efficient information and decision-support systems for container transportation logistics, and Antush (1989), who emphasizes the need for developing new information systems and planning methodologies for container transportation.

In a recent survey of the literature on fleet management models in freight transportation, Dejax and Crainic (1987) noted, however, that relatively little effort was directed toward developing models aimed specifically toward container transportation issues, with the bulk

of the work in the area being dedicated to the maritime aspects of the problem. Thus, Dejax and Crainic quote a few authors who addressed the problem of the empty container distribution as that of allocating containers available in surplus at a terminal, from earlier loaded shipments, to demanding terminals (e.g. a customer's warehouse, a rail yard, or a port), in preparation for subsequent loaded movements. Anthonisse (1988), who addresses the worldwide maritime container fleet management problem, is a recent example of such efforts.

The state of the art described by Dejax and Crainic may be explained, at least partially, by the combined effect of the relative complexity of the container land transportation issues and the opinion, prevalent until very recently in the industry, that the impact of land operations on the overall company's performance was marginal. This perception is, however, gradually evolving and, especially in today's increasingly competitive environment where growing customer demand is associated to the search for cost-efficient high-quality-service operations, the land portion of the container journey is receiving increasing attention.

We aim to answer some of these challenges by developing models, procedures, and tools to assist in the analysis, evaluation and planning of the land transportation of containers for international maritime shipping. The goal of this paper is to present an overview of the models and methodology that we propose for the global, integrated planning of the land distribution and transportation of containers. We focus, in particular, on the modelling framework that we propose for the operational planning of the land distribution and transportation of loaded and empty containers.

The paper is organized as follows. In the first section, we give a general description of the issues related to the land movements of containers. The overall planning approach, which integrates the models for the strategic/tactical and operational planning level, is presented in the second section; we briefly refer in this section to our previous modelling efforts and results at the strategic/tactical levels. The following two sections correspond to the core of the paper and describe the main characteristics of the operational decision-support system, and modelling framework for the empty container allocation problem. Our conclusions indicate future research directions in this area.

PROBLEM DEFINITION

Our research is motivated by the analysis of typical land transportation problems encountered by international maritime shipping companies that operate maritime and land networks of considerable, even continental, scale. Thus, in our initial application, the company operates worldwide maritime shipping lines to and from some twenty major European ports, while the land distribution and transportation network covers France, the Federal Republic of Germany, Holland, Belgium and Luxemburg. In 1986, this represented some 250,000 land container movements, which correspond to about 80% of the total movements of containers the company performed in Europe in that particular year (Dejax *et al.*, 1988).

Arriving ships carry containers of two sizes and about ten major types each, loaded with imported goods, as well as empty containers returning back to Europe from previous exports. Loaded containers must further be transported to their final destination, usually an industrial firm or a food distribution center located somewhere in the western European continent. Ground transportation modes are of various types, including rail, truck, barges and mixed modes. This latter mode usually consists of an initial railway shipment to an inland railway terminal, followed by a final movement by truck to the customer. The empty containers that are imported may either stay at the port for a while, or be immediately dispatched wherever they are needed for subsequent exports.

After importation, the unloaded empty containers present at the customer's site may either return to the port of origin, either directly or via a railway terminal, or be transported to any other depot: port or inland terminal. This return shipment may, but more often than otherwise will not, be made using the same vehicle (truck, railway car ...) that has been used for the transportation from the port to the customer.

Similarly, exporting industrial firms need empty containers to be delivered to them, either from the future export port, or from any other location. Due to complex organizational considerations, very few (some 3%) empty container movements are made directly from import to export customers. After loading, containers are transported to the export port, either directly or by mixed mode through a railway inland terminal. Finally, these export containers are loaded on ships together with empty containers sent abroad to cope with the worldwide imbalance in the supply/demand of certain types of container.

One notes the importance of empty container movements. First, every commercial (profitable) movement of a loaded container generates almost automatically a non-profitable, technical empty container movement: once a loaded container delivered to a customer's site has been unloaded, it normally has to be moved away empty to a certain depot, while an empty container has to be delivered to an exporting customer.

In addition, significant regional imbalances between imports and exports within the area served by the company (their amplitude may vary according to the container type and the geographical subdivisions considered), as well as possibilities of reduction in costs due to mass transportation of containers over relatively long distances (by railway, for example) result in land movements of empty containers directly between depots aimed at correcting these unbalances.

Thus, by their impact on the resource requirements and on the quality of service offered to the company's customers, empty movements play a central role in the management of the land distribution and transportation of containers. To illustrate this with a few figures, we can say that, for a major European shipping company, some 250,000 land container movements were made in 1986, representing an estimated total distribution and transportation cost of some $ 40,000,000 U.S. Of these, 40% (95,000) were empty movements! Among the 130 possible depot locations, 90 inland terminals or ports have actually been used by the company for the collection, storage and distribution of these containers.

Among the key questions addressed by maritime shipping companies for the organization of their distribution and transportation operations on land, we can mention:

- Which inland terminals should be used for the collection and distribution of empty containers?
- For each customer and container type, where should empty containers be returned to after import, and from which depot should empty containers be sent to a customer prior to export?
- Should massive movements of empty containers be undertaken between depots to equilibrate supply and demand? Between which depots, in what quantities and at what cost?

- How to evaluate the needs and availabilities for empty containers?
- How to choose the transportation mode and carriers to undertake the shipment of loaded and empty containers between ports, or depots, and customers and vice versa, or between two depots?
- How should a given company cooperate with sister shipping companies to pool their container parks and achieve a better overall operation?
- How to achieve the management and dispatching of the fleet of containers, loaded and empty, in order to satisfy the known and forecasted demand and to perform the planned interdepot empty container movements, while considering the uncertainties associated with the supply, demand and transportation, and the fact that transportation costs and reliability may vary considerably due to the use of many independent local carriers?

These issues clearly belong to several planning levels: strategic (e.g. the selection of inland terminals), tactical (e.g. the determination of the interdepot empty flows) and operational (e.g. the dynamic dispatching of containers). They cannot all be represented by a single model. Moreover, they do not require the same data, neither do they require the same personnel and resources for their planning and execution. Hierarchical relations exist among them and are reflected in the flow of information and decisions. However, the fact that container shipping companies do not often need to build expensive inland terminals (they may in fact use already existing terminals, such as rail yards, for a cost much lower that the cost of building their own facilities), thus permitting them to periodically reevaluate the decisions concerning the inland terminals to use and the corresponding allocation of customers to depots. An integrated, multilevel methodology may then be designed in order to attempt to answer these questions. We have developed such a methodology, which is outlined it in these pages.

OVERALL PLANNING APPROACH

We propose a two-level approach for the global, integrated planning of the land distribution and transportation of containers, which reflects the observed hierarchy in the decision process and the flow of information. Figure 1 illustrates a schematic representation of this approach.

The topmost level is concerned with the *strategic/tactical* planning of operations. The main issues that are considered at this level are the choice of the depots, the allocation of customers to depots for each type of container and for each direction of movement, and the determination of the major interdepot flows of empty containers. The planning horizon of these decisions generally covers a six to twelve-month period. The main data requirements are the global demand forecasts, plus the general characteristics of the system, possible depot sites, fleet size and composition, etc., suitably aggregated.

The so-called (strategic/tactical) *transportation plan* is the main output of this phase. The transportation plan will guide the actual operations of the system. It is also a privileged way of evaluating, in terms of system performance and network and fleet utilization, the consequences of various strategic scenarios concerned with the evolution of the company and with variations in its environment: demand, competition, laws and regulations, etc.

The second component of our approach corresponds to the level of the *operational* planning of the company's activities. At this level, one has to make sure that demand is satisfied and that the most effective routes and means of transportation are selected and used. Major factors that characterize this level of planning are the dynamic and stochastic environment and the guidelines established by the strategic/tactical plan.

The purpose of this paper is to outline the *operational decision-support system* and its two main components, the empty container *allocation* model and the model for *routing* loaded **and** empty containers. In this section, we only briefly mention the main characteristics of the other components of the planning approach.

The strategic/tactical model may be formulated as a multimode, multicommodity location/distribution problem with interdepot balancing requirements (Crainic *et al.*, 1989a). Several variants of this formulation, which correspond to various policies of

allocating customers to depots, have been studied, and we noted a few similarities with classical location problems. Yet, all variants displayed a number of very interesting characteristics. Among these, the most significant is the network structure of the problem which emerges in all formulations. This has prompted the development of specifically tailored algorithms which are more efficient than general purpose methods for location problems with additional constraints.

For this model, we developed efficient branch-and-bound (Crainic *et al.*, 1989c) and dual based algorithms (Delorme *et al.*, 1988). The combination of the branch-and-bound structure with bounds computed by the dual procedure (Crainic *et al.*, 1988; Delorme *et al.*, 1989) has also proved to be extremely interesting from a computational point of view. We are currently working on Lagrangean relaxation-based algorithms (Guo *et al.*, 1989) and on methods integrating restriction approaches and primal/dual principles (Tétreault *et al.*, 1989), which make full use of the network flow structure of the problem. The efficiency of the algorithms guarantees that the strategic/tactical problem may be solved as often as required by the fluctuations of demand, or by the modifications of the economic or legal environment.

The output of this model consists of the set of depots to be used for the next planning period, of the allocation of each customer to a specific depot, or to a specific set of depots, for each container and transaction (demand or return of empty containers) types, and of the main empty container interdepot flows required to correct the demand/supply differences which exist among the various regions of the network. Note that, when a customer is assigned to more than one depot for the same container and transaction types, the transportation plan also indicates how the flow is to be split.

This information may be used to evaluate a strategic scenario represented in the strategic/tactical model. In actual operations, however, following its validation and approval, it is transmitted to the operational level. Here, the tactical transportation plan is used in several ways, the goal always being to aim toward operational decisions, taken locally in a dynamic environment, which are "close" to the optimal choices that were globally determined for the whole system.

As illustrated in Fig. 1, several other types of information have to arrive from the company's information system and enter the operational planning module. In particular, data on demand is to be given, both the short-term forecasts and the known supplies and demands for the forthcoming period (Crainic *et al.*, 1989b, present preliminary results concerning demand models in this context). Equally essential are the rules that specify how transportation means are chosen and priced, plus the company's own accounting criteria concerning the various costs related to owning and using containers. In the following sections, we further discuss the information needs of the operational planning module, which is a decision-support system in its own right.

The main output of the operational planning system consists of decisions concerning the allocation of empty containers to customers, the transportation of loaded and empty containers between depots (and ports) and customers and the interdepot empty container balancing flows. This data, as well as information needed to update demand and cost models, has to be fed back to the information system, for accounting and statistical purposes and for use in other company departments, and also for the update of the information required by the strategic/tactical model and the operational model at later periods.

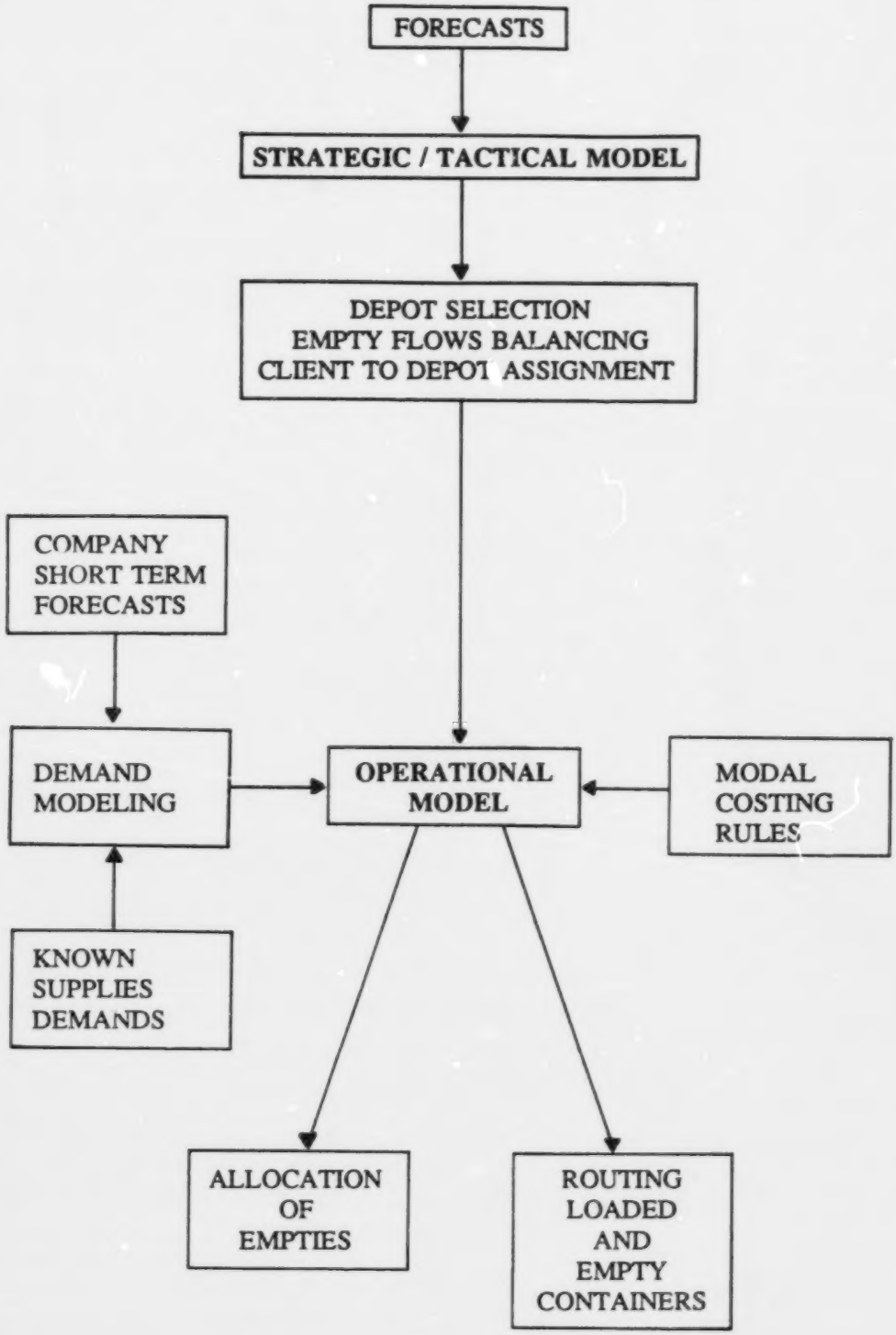

Fig. 1 The Overall Planning Approach

THE OPERATIONAL DECISION-SUPPORT SYSTEM

As stated above, at the operational level, our objective is to provide decision-makers with a comprehensive tool which will give them answers to the critical questions arising in the day-to-day management of a container fleet on land:

(1) How should customers' demands for empty containers be satisfied ?

(2) Which level of inventory of empty containers of each type should be maintained at each depot to face unexpected demands ?

(3) When should major interdepot movements required by the strategic/tactical plan to equilibrate overall flows on the network be carried out ?

(4) When should the company buy new containers or borrow from partner companies ?

(5) How should loaded and empty containers be moved between customer locations, ports, and depots ?

In most cases, these questions can further be broken down in a number of subquestions. For instance, with regards to question (1), one has to determine not only the depot from which the empty containers will originate, but also the exact type of these containers, since substitutions are possible in some cases, and the timing of the delivery to the customer, since there is usually some freedom at that level.

Ideally, one would like to develop a single mathematical model to optimize the short-term land operations of the company, in order to fully account for the interactions between the various decisions to be made. Given the intrinsic complexity of the problem at hand and the current state of the art in O.R., this is not feasible. The solution which we propose is to break down this large problem into two smaller problems, an *empty allocation problem* and an *empty and loaded routing problem*, and to develop a separate optimization model for each of them.

The allocation model deals with questions (1) to (4), i.e. its aim is the determination of the "best" distribution of empty containers that satisfies both known and forecasted customer demands. Economic criteria guide the search for solutions which have to respect the strategic/tactical objectives and policies of the company. To allow for the high level of uncertainty inherent in the real-time operation of a transportation system and for the impact of current decisions in the future, it is a stochastic, dynamic model which covers a

planning horizon of one to two weeks. In practice, it should be used as a rolling horizon model of which only the first period (say one day) decisions are implemented. There are two stochastic elements in the model: empty container demand and empty container supply. For each customer zone, each container type and each period of the planning horizon, the probability distribution of the number of supplied and demanded containers is estimated by a stochastic module which combines information on known and forecasted empty and loaded movements taken in the company's M.I.S. with results from previous demand forecast analyses. The main output of the allocation model is a list of empty container allocations and movement requests for the first period of the planning horizon.

The routing model strives to minimize the overall transportation cost of the loaded and empty containers from their origin to their destination. The inputs to this model are the list of empty movement requests produced by the allocation model and a list of loaded movement requests coming from the company's M.I.S., as well as detailed data on the available transportation alternatives. These data include cost, distance, and time information for the various possible transportation modes (rail, road, mixed, etc.), the different carrier contract options (one-way, two-way, circuit, etc.), the transportation regime for each movement (which indicates whether the customer or the shipping company is responsible for it), and the specification of customer transportation arrangements with regards to mode (direct link with the railway network, for example) and to pick-up and delivery schedules.

It is worthy to note that, since the container shipping company does not own, in any significant measure, the required land transportation means, substantial savings can be achieved by using a routing module. This is particularly true for truck transportation where most savings are achieved by generating multi-stop "circuit" truck routes and by suitably matching requested container movements to these routes.

The output of the routing model is a list of *movement orders* which completely describe the loaded and empty movements to be executed during the next period (day). This information is fed back to the company's M.I.S. to update the information on known and forecasted movements. Figure 2 summarizes the information flow at the operational level.

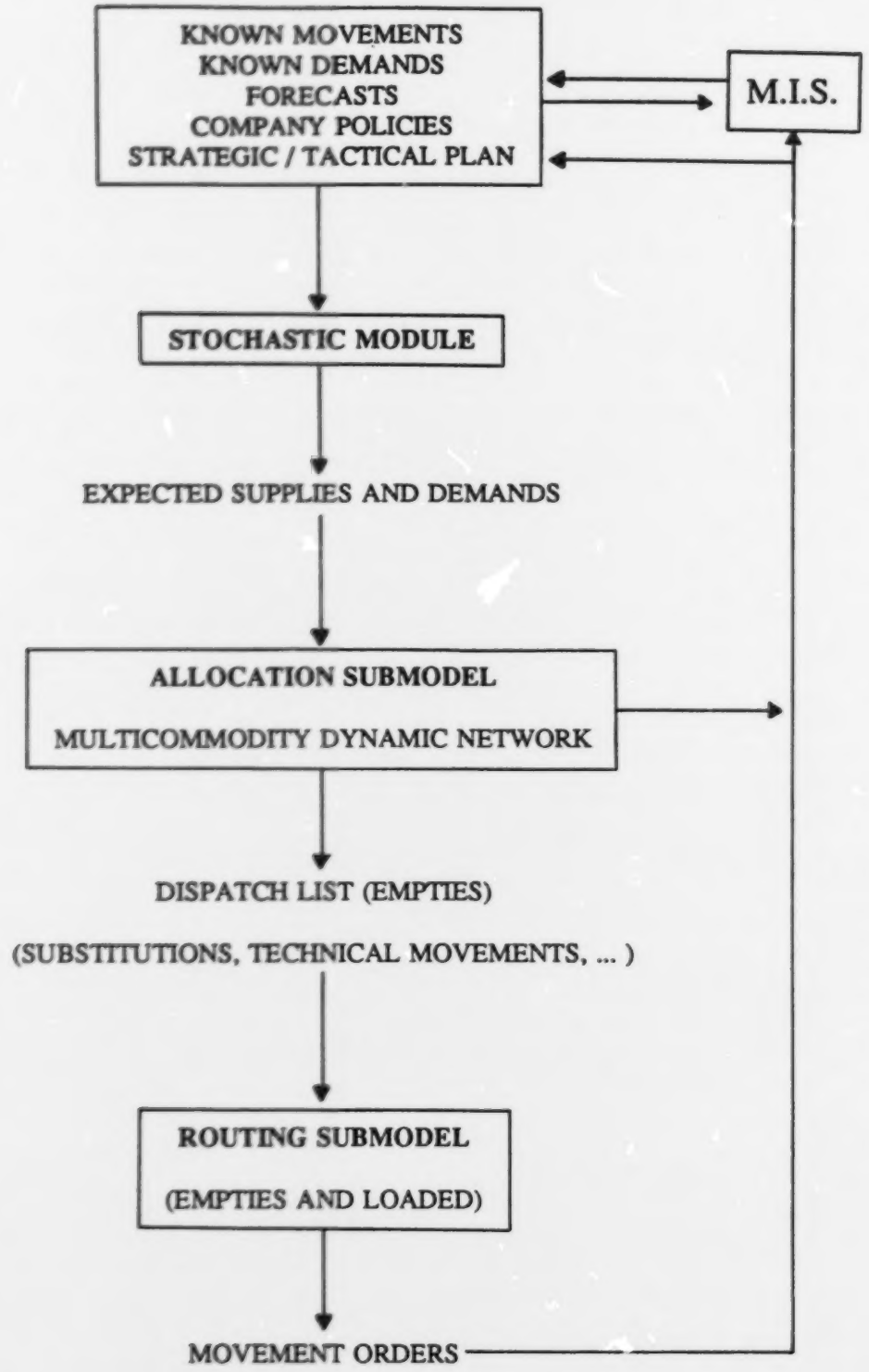

Fig. 2 Outline of the Operational Decision–Support System

THE ALLOCATION MODEL

The allocation model is truly the "heart" of the operational level decision-support system. In this section, we do not present a detailed mathematical formulation of this model. Rather, we examine the main elements that go into it, analyze briefly the relationships between this and other fleet management problems, and outline the network formulation.

Main Elements of the Problem

A great deal of information goes into the empty container allocation decision process. Here are the main items of this flow of information:

- The *strategic/tactical plan*. It specifies the current network configuration: the depots that are to be used, the allocation of the customer zones to depots and the main inter-depot flows of empty containers required to equilibrate the demand on the network. Interdepot flows are specified by container type. The allocation of customers to depots is also specified by container type and, additionally, by direction of movement (customer to depot and depot to customer). In general, a customer may be related to several depots for each type of container and each direction of movement. Then, the strategic/tactical plan indicates the relative importance (proportions) of these flows.

- *Empty container supply*. Loaded containers normally arrive in ports and have to be moved from there to their final destinations (customers). The decision of how to move them is taken simultaneously in the routing model with the corresponding decision concerning empty containers. Once at the customer's site, they are unloaded; later, the empty containers normally have to be moved to the assigned depot. This decision is again taken by using the routing model. Thus, the input of loaded containers into the system has a significant impact both on the routing issues and on the future *supply* of empty containers at depots. This is an important issue due to its influence on the inventory levels in depots and on the subsequent allocation decisions. The issue is complicated by the presence of several stochastic factors: the arrival date in port, the ship unloading delay, the various transportation delays and, last but not least, the time the containers spend at the customer's site. This last factor displays the most stochastic behavior of the four and is the one which is the most delicate to evaluate,

especially when it is the customer who is in charge of moving the containers from the port and then back to the depot. The supply component of the stochastic module addresses these issues.

- *Empty container demand*. Demand is indicated for each type of container, for each customer or customer zone and for each period of the planning horizon. Some of these demands are known and can be considered explicitly in the allocation model (demand nodes). The demands of some other customers are known with less certainty, especially as the period where the demand is expected is farther down the temporal axis. Finally, it is known that, in each region and for each type of container, there is a nonzero probability that an unforecasted demand will pop up in some future period. These two types of stochasticities are considered in the stochastic module, where the expected demands are computed and the empty container demand distributions, by region/customer and type of container, are determined.

  For each customer's demand, one also generally knows the *distribution-time window* within which it has to be satisfied. At this level of planning, it is noteworthy that this characteristic precludes the existence of backorders in the system. The distribution-time windows are mainly determined by the due date in port (determined by the ship schedules) and estimations of the time necessary to load the containers and to transport them. These windows are explicitly considered in the allocation model.

- *External movements of empties*. Differences between the supplies and demands of containers of certain types exist not only at the national or regional level, but also at the level of the international trade. Therefore, one notes arrivals of empty containers from outside the zone of the study (normally, by ship), as well as requests that empty containers be shipped outside the zone. These events are reasonably well known in advance, subject to the transportation uncertainties on land and on maritime routes, and are taken care of in the stochastic module.

- *Substitution rules* for containers. These may vary by customer since they depend upon the specific commodity that is transported. For example, two twenty-feet containers may be substituted for a 40-feet container, if shoe boxes are to be moved; yet, the same rule does not apply for anything lengthier that twenty feet. Substitutions are

handled through special arcs in the allocation model and final adjustments at the routing level.

- *Costs* for transportation, holding–inventory, stockouts, etc.
- *Marginal costs* of empty containers at depots. Computed initially by the strategic/ tactical model, they are continuously updated by the allocation submodel.
- Total *fleet dimension* and its current position.
- *External affairs* rules concerning possible exchanges with the partner container shipping companies, renting of empty containers, acquisition of new ones, etc. Estimation of distributions for the breakdown of containers, either definitively (when they are scrapped and go out of the system) or temporarily (an estimation of the expected repair time is then needed), falls also in this category.
- The *stochastic* characteristics of the various transportation modes and itineraries, of various port (and terminal) operations and delays, and of the time spent at the customers' sites.

Besides the list of empty container movement requests, several important bits of information and decision factors are expected out of the allocation model. Among these, the most important are:

- *Decisions* that are related to the list of movements and that concern
  - the substitution of containers,
  - the number and types of containers from partner companies that enter the system,
  - the number and types of containers that are loan to the partner companies,
  - the new containers that have to be bought,
  - the containers that have to be rented and returned, etc.
- *Demand distribution update*. The information concerning the demand that has actually materialized is fed into the stochastic module to update the various distributions and the expected values for the following periods.

- *Marginal values* for the various types of containers, at various time periods and locations. This allows to determine the relative value of a customer demand (or offer), as well as values for containers both present in the inventory and out of stock.

These elements are also specified for the entire planning horizon. It is important to note, however, that only the movements and decisions pertinent to the current period are of actual interest and are transmitted to the routing module and to the other components of the decision-support system. The other elements of information, which correspond to periods following the current one until the end of the planning horizon, present an interest from an analysis point of view (''what is the forecasted evolution of the system over the planning horizon?''), but are not considered for decision purposes.

Relations with Other Fleet Management Problems

Operational fleet management problems with uncertain demands occur in other segments of the transportation industry, most notably in railway and trucking companies. In recent years, these problems have received a fair level of attention from operations researchers which has led to the development of a number of stochastic, dynamic models to handle them (see Dejax and Crainic, 1987, and Gendreau, 1988, on this topic). The specific problems addressed by these models can be classified in two broad categories:

(1) *Empty vehicle redistribution problems*

In these problems, which are typical of rail freight transportation, one tries to reposition empty vehicles optimally to fill stochastic demands, with unfilled demands in one period being carried over to the next one at some cost. Future supplies of vehicles available for distribution are also usually highly stochastic. Typical examples of this class of problems may be found in Jordan and Turnquist (1983) and Beaujon and Turnquist (1988).

(2) *Dynamic vehicle allocation problems*

These problems which have been extensively studied by Powell (see Powell, 1988, for a review of various model formulations) are generally encountered in the truckload motor carrier industry. They differ from the previous type in that one may turn down

unprofitable loads and that unfilled demands are lost. A critical implication of this situation is that one must consider both empty and loaded movements in the optimization process.

With regards to this classification, the empty container allocation problem clearly falls in the first category above and it does share with these problems a number of fundamental characteristics (the most notable of them being that loaded vehicles "disappear" from the network). However, it differs in many ways from problems previously studied. The most important of these differences has to do with the existence of many vehicle (container) types which have to be considered simultaneously because of the possible substitutions, while other models only consider one type of vehicle in isolation. This is a critical feature since it adds another ''layer of complexity'' to the problem. The handling of demand is also quite different: in our problem, demand must absolutely be met (within a time frame of a few periods) and there is no provision for backorders. The existence of the strategic/tactical plan with its requirements for equilibration flows, the container exchanges with the partner companies, and the possibility of buying new containers are other interesting features which are not found in similar problems.

The Network Formulation

As previously indicated, the structure of the formulation may be described as a *dynamic network* model over a *rolling horizon* of *n* days or periods. This is a space-time description of empty container movements for every container type. Inputs to this model are provided by the stochastic module, which mainly computes the distributions and expected values of demands, and by several bookkeeping procedures for, among others, the treatment of loaded containers, return of rented ones, etc.

Besides its temporal dimension, the model has a spatial, geographic significance linked to the territory covered, and a vertical, multilayer structure that represents the multicommodity (each container type corresponds to one commodity) aspect of the problem. Thus, for each period and type of container, the network representation includes as nodes the set of ports and depots, the known customers and zones where demand might pop up. To facilitate the modelling of container substitution decisions, two nodes are associated to each supply point (port, depot, etc.): one that represents the proper supply of the container type considered in

the current layer, and another that is the end node of arcs representing possible substitutions of other container types.

For each period and container type (layer), transportation and distribution links connect the nodes. The commodity layers are linked through substitution arcs which enforce the rules of the company. The "dynamic" arcs, which connect the network representations on the temporal axis, are of various sorts: transportation, when the expected transportation delay is longer than one period, holding, when containers are kept at their present location (depot or customer), etc. These arcs may link periods that are more than just one day apart. Links which represent the customer distribution-time windows are a perfect illustration of this case: an arc joins the supply node in each of the periods of the distribution window to the customer node of the last period of the window.

The special structure and properties of the container land transportation problem require that a number of issues be addressed in order to achieve a comprehensive modelling framework: substitutions, distribution windows, interdepot balancing flows, relations with the outside world (partner companies, acquisitions, and so on), etc. We did address all these issues by combining in our modelling framework the design of the dynamic network with bookkeeping procedures and with procedures for the estimation of supplies, demands, and various link lower bounds and capacities. Some of these bounds are known and are provided by the bookkeeping mechanism. However, most of them are random variables, and their respective probability distributions and expected values are computed by the stochastic module.

Two cases of such particular problems are the consideration of "massive" interdepot flows required to equilibrate the network and the substitution decisions.

Guidelines for equilibrating the network supply and demand by using interdepot flows come from the strategic/tactical model. In the allocation model, the disequilibrium state of the network is qualified each time the planning horizon is rolled and, according to the container marginal values at each depot, a decision is made concerning the interdepot movements. The bookkeeping procedures add the necessary arcs and specify the deterministic bounds on these arcs.

Substitution decisions are handled by introducing in the network arcs which represent possible substitutions between various container types. The particulars of each case and time period are reflected by the capacities that are assigned to each substitution arc. These capacities are random variables, and their probability distributions and expected values are updated each time the planning horizon is rolled.

We conclude this section with a general comment concerning the possible solution methods that may be used in conjunction with this formulation. Stochastic network methods (Frantzeskakis and Powell, 1989) offer an interesting and challenging approach. Equally appealing is the approach where a deterministic network problem is solved, where the expected values stand for the respective random variables, and suitable bounds are imposed on stocks of containers at nodes. We plan to develop, test, and compare the two methods.

CONCLUSION

We have presented a global planning approach for the land distribution and transportation of containers, in which the inherent complexity and specificity of the problem have been accounted for. As it stands now, most of the relevant modelling issues have been addressed, but a considerable amount of research work still remains to be done, especially with regards to the development of solution procedures at the operational level, before one may contemplate the full practical implementation of this approach.

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